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(54) Title of the Invention: Substrate Alignment Method

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# SPECIFICATION

## 1. Title of the Invention

Substrate Alignment Method

## 2. Scope of Patent Claims

An alignment method for photoelectrically detecting optical information generated from an alignment mark, which is formed on a substrate so as to have a geometric or optical change, by an electro-optical scanning device, and processing a time-series photoelectric signal of which the intensity changes with respect to a relative scanning direction of the alignment mark, thus determining the position of the alignment mark in the relative scanning direction, characterized in that the method comprises: a process for obtaining the photoelectric signal having a waveform with extreme values at a pair of mark edge portions which define the width in the relative scanning direction of the alignment mark from the electro-optical scanning device, a first determination process for determining the position of the alignment mark based on a pair of slope waveform portions existing at an inner side of the two extreme values of the photoelectric signal waveform; a second determination process for determining the position of the alignment mark based on a pair of slope waveform portions existing at an outer side of the two extreme values of the photoelectric signal waveform; a third determination process for determining the position of the alignment mark based on slope waveform portions existing at both the inner and outer sides of

the two extreme values of the photoelectric signal waveform; and a process for selecting any one of the first determination process, the second determination process, and the third determination process in accordance with a targeting alignment precision of the substrate.

3. Detailed Description of the Invention

Industrial Field of Utilization

The present invention relates to a method for performing alignment by photoelectrically detecting an alignment mark formed on a semiconductor wafer, a plate for liquid crystal displays, or the like.

Prior Art

Convetionally, when positioning (alignment) a wafer, a plate, and the like, a method of photoelectrically detecting an alignment mark formed at a predetermined position on a substrate through the objective lens of a microscope has been used.

The photoelectric detection method is roughly classified into two methods. One is a light beam scanning method in which the mark is relatively scanned by the spot of a laser beam or the like, and scattering light beams or diffracted light beams generated by the mark are received by a photomultiplier, a photodiode, or the like. The other method utilizes an image signal of a mark obtained by a television camera (Vidicon tube or CCD) imaging the mark uniformly illuminated to obtain an enlarged image thereof.

In either case, the photoelectric signal obtained thus is subjected to waveform processing to obtain the central position of the mark.

Although the light beam scanning method and the imaging method have completely different structures in their scanning systems, in this specification, both of the scanning systems will be considered as being an electro-optical scanning device (hereinafter referred to as EOS (Electrical-Optical Scanner)).

Among such EOS systems, as a method of detecting the mark position by moving a wafer stage one-dimensionally with respect to the laser beam spot, there is known a technique such as disclosed in US Patent Nos. 4,655,598, 4,677,301, and 4,702,606, for example.

In addition, as a method of detecting the mark position within the one-dimensional scanning range of a scanning beam with a wafer stage positioned according to a designed value, there is known a technique such as disclosed in US Patent Nos. 4,390,279 and 4,566,795, for example.

In addition, as an EOS system using the imaging method, there is known a technique such as disclosed in US Patent Nos. 4,402,596, 4,679,942 and 4,860,374, for example.

In these conventional techniques, monochromatic light is used as the scanning beam or the mark illumination light for the two main reasons given below.

(1) A projection exposure apparatus (stepper) of the type which detects a wafer mark through a projection optical system uses single-wavelength illumination light or a laser beam in order to avoid large chromatic aberration of the projection optical system.

(2) A monochromatic laser beam is used to obtain a small focusing spot so that high-luminance and high-resolution detection can be realized.

When monochromatic illumination light (or a beam) is used as set forth above, a relatively large S/N ratio can be obtained. However, since in wafers handled by the exposure apparatus, a photoresist layer with a thickness of 0.5 μm to 2 μm is usually formed on the entire wafer surface, an interference phenomenon occurs due to the monochromatic properties, and this often results in detection errors in detection of the mark position or makes a resulting image unclear.

In this context, proposals have been made in recent years to use a multi-wavelength or wideband illumination light in order to reduce the interference phenomenon caused by the resist.

For example, in an EOS system using the imaging method, when illumination light is generated by a halogen lamp or the like, and the wavelength bandwidth thereof is set to approximately 300 nm (excluding the photosensitive region for the resist), there is almost no coherence in the rays themselves reflected from the resist surface and the wafer surface. Thus, it is possible to detect a clear image. Therefore, in the imaging method, by only using white (wideband) illumination light and an achromatic imaging optical system, it is possible to obtain an extremely accurate alignment sensor which is not affected by the resist.

Problems to Be Solved by the Invention

As described above, when generation of an interference fringe is suppressed by using polychromatic or white illumination light, and detection of a clear image is enabled, factors causing small errors which have been neglected or unnoticed have been focused on.

In other words, since the step structure of the alignment mark is detected more clearly, the detection or alignment precision is affected by a slight difference in the profiles of the mark edges.

In the past, various algorithms have been used for image signal processing. However, neither of the algorithms has taken into consideration a slight change in the mark edge profiles, and the algorithms had their own limit in improving the overall alignment precision.

The present invention is designed in consideration of such problems, and the object thereof is to improve the alignment precision.

Means to Solve Problems

The present invention relates to a method of photoelectrically detecting optical information generated from an alignment mark on a substrate such as a wafer by an electro-optical scanning device such as a television camera or a scanning laser and processing a time-series photoelectric signal (image signal) of which the intensity changes with respect to a relative scanning direction of the alignment mark, thus determining the position of the alignment mark.

According to the present invention, the method includes the processes given below: a process for obtaining the photoelectric signal having a waveform with extreme values at a pair of mark edge portions which define the width in the relative scanning direction of the alignment mark from the electro-optical scanning device, a first determination process for determining the position of the alignment mark based on a pair of slope waveform portions existing at an inner side of the two extreme values of the photoelectric signal waveform; a second determination process for determining the position of the alignment mark based on a pair of slope waveform portions existing at an outer side of the two extreme values of the photoelectric signal waveform; a third determination process for determining the position of the alignment mark based on slope waveform portions existing at both the inner and outer sides of the two extreme values of the photoelectric signal waveform; and a process for selecting any one of the first determination process, the second determination process, and the third determination process in accordance with a targeting alignment precision of the substrate.

Action

In the present invention, basically, the signal waveform processing is performed as shown in FIG. 2.

FIG. 2(A) shows the cross-sectional structure of a convex mark MK formed on a wafer W with a resist layer PR uniformly coated on the surface thereof.

FIG. 2(B) shows the waveform of a video signal VS when an image of the mark MK was captured by a television camera along a scanning line that passes across the edges E1 and E2 at both ends of the mark MK. This video signal VS represents the bottom waveform portions BW1 and BW2 which have minimum values at the positions of the edges E1 and E2 at both ends of the mark MK. The waveform level between the bottom waveform portions BW1 and BW2 varies depending on the reflectance of the mark MK itself, and the waveform level on the left side of the bottom waveform portion BW1 and the waveform level on the right side of the

bottom waveform portion BW2 vary depending on the reflectance of the wafer substrate.

FIG. 2(C) is an enlarged view of the two bottom waveform portions BW1 and BW2. The bottom waveform portion BW1 has a down-slope portion DSL1 which falls down to the bottom level BT1 as the scanning advances, and an up-slope portion USL1 which rises from the bottom level BT1 as the scanning advances. Likewise, the bottom waveform portion BW2 has a down-slope portion DSL2 which falls down to the bottom level BT2 and an up-slope portion USL2 which rises from the bottom level BT2. In the present invention, the central position of the mark MK with respect to the scanning direction is determined by selectively using the slope portions DSL1, USL1, DSL2, and USL2 of the bottom waveform portions BW1 and BW2 corresponding respectively to both edges E1 and E2 of the mark MK.

In each of the slope portions, those slope portions existing at the inner side are the up-slope portion USL1 and the down-slope portion DSL2, and those slope portions existing at the outer side are the down-slope portion DSL1 and the up-slope portion USL2.

In actual processing, for one bottom waveform portion BW1, the scanned position P1 where the slope portion DSL1 coincides with a slice level S1 which divides the values between the peak value at the shoulder of the down-slope portion DSL1 and the bottom level BT1 by a predetermined ratio (50%, for example), and the scanned position P2 where the slope portion USL1 coincides with the slice level S2 which divides between the peak value at the shoulder portion of the up-slope portion USL1 and the bottom level BT1 by a predetermined ratio are calculated.

Likewise, for the other waveform portion BW2, the position P3 obtained by comparing the down-slope portion DSL2 with the slice level S3 and the position P4 obtained by comparing the up-slope portion USL2 with the slice level S4 are determined.

Therefore, the computation of the central position Pm of the mark MK is basically performed in accordance with any one of the three equations given below.

$$Pm=(P2+P3)/2 \quad \ldots (1)$$

$$Pm=(P1+P4)/2 \quad \ldots (2)$$

$$Pm=(P1+P2+P3+P4)/4 \quad \ldots (3)$$

Here, equation (1) is the basic expression of the inner slope determination method; equation (2) is for the outer slope determination method; and equation (3) is for the both-slope determination method.

In the present invention, the alignment of a wafer is executed by selecting the determination method which optimizes the precision when the wafer was actually aligned, for example.

Embodiments

Hereinafter, with reference to FIG. 1, the structure of a projection exposure apparatus suitable for implementing the method according to an embodiment of the present invention will be described.

In FIG. 1, an image of a pattern area PA on a reticle R is projected through a projection lens PL and formed on a wafer W. The wafer W is mounted on a stage ST that moves in the X and Y directions by the step-and-repeat method, and the coordinate position of the stage ST is measured by interferometers IFX and IFY. The reticle R is aligned with respect to the apparatus (the optical axis of the projection lens PL) by positioning reticle alignment marks RM1 and RM2 provided at both sides of the pattern area PA with respect to reticle alignment microscopes RAS1 and RAS2. In addition, marks (windows) for the die-by-die alignment are formed in a region corresponding to the peripheral street lines of the pattern area PA. The marks (windows) are detected by TTR (through-the-reticle) alignment microscopes DAS1, DAS2, DAS3, and DAS4 together with wafer marks for the die-by-die alignment attached to each shot area on the wafer W.

In this specification, the method according to the present embodiment is applied to a wafer alignment sensor which detects only the marks on the wafer W by the off-axis method. This wafer alignment sensor includes a mirror 10 arranged in the close vicinity of a position below the projection lens PL, an objective lens 12, a beam splitter 14, an imaging lens 16, a conjugate index plate 18, an image pickup lens 20, and a CCD two-dimensional image pickup element 22. In addition, in order to illuminate the mark area on the wafer W, there is provided an illumination optical system including an optical fiber 24 which induces wideband light emitted from a halogen lamp, a high-luminance polychromatic LED or the like, a condenser lens 26, an illumination field diaphragm 28, a lens system 30, and the beam splitter 14 which has been mentioned earlier.

In the above-mentioned structure, the wafer W is arranged to be optically conjugate to the index plate 18 in relation to the objective lens 12 and the combined system composed of the objective lens 12 and the imaging lens 16. Moreover, the wafer W is arranged to be conjugate to the index plate 18 and the light receiving surface of the CCD 22 in relation to the image pickup lens 20.

Therefore, the CCD 22 images the mark on the wafer W to obtain an enlarged image thereof and images the fixed (reference) mark on the index plate 18 to obtain an enlarged image thereof simultaneously. In addition, the emission end surface of the fiber 24 of the illumination optical system is relayed as a secondary light source image to the pupil plane (the position of an aperture diaphragm) between the objective lens 12 and the lens system 30 to provide Kohler's illumination to the wafer W. Furthermore, the field diaphragm 28 is conjugate to the wafer W by the combined

system composed of the objective lens 12 and the lens system 30, and the aperture image of the field diaphragm 28 is conjugate to the wafer W. Accordingly, the aperture image of the field diaphragm 28 is projected onto the wafer W. In the present embodiment, at least the objective lens 12, the imaging lens 16, and the image pickup lens 20 are made achromatic so as to suppress deterioration of the imaging characteristics due to chromatic aberration.

In addition, in the apparatus according to the present embodiment, a reference mark FM is provided on the stage ST and is used for measuring the distance (baseline) between the projection point on the wafer W of the index mark on the index plate 18 in the wafer alignment sensor and the projection point of the reticle alignment marks RM1 and RM2 on the reticle R or the marks for the die-by-die alignment.

Next, with reference to FIG. 3, the processing circuit for the video signal from the CCD 22 shown in FIG. 1 will be described. The CCD 22 is a two-dimensional image pickup element with picture elements (pixels) arranged in the horizontal and vertical scanning directions. In the CCD 22 of the present embodiment, however, the horizontal scanning direction is assumed to coincide with the direction crossing the edges of the mark on the wafer W.

From the CCD 22, a composite video signal, which is a mixture of the horizontal synchronization signal and vertical synchronization signal, is obtained. This video signal is transferred to an analog-digital converter (ADC) 42 via a pre-processing circuit 40 such as a frequency filter or an AGC. On the other hand, the video signal from the CCD 22 is also transferred to a control circuit 44 including a synchronization signal separator circuit, a clock generator circuit, and the like. This control circuit 44 outputs a clock signal SCL in accordance with the horizontal synchronization signal from the CCD 22 such that one clock pulse is generated for each electrical scanning (readout scan) of one pixel. This clock signal SCL is transferred to a comparator 46, which detects whether or not the electrical scanning of the CCD 22 has covered the sampling range (the number of horizontal scanning lines in the vertical direction) in one frame, and to an address counter 48 which outputs an address value to a memory (RAM) 43 for storing the output data from the ADC 42. Therefore, in the RAM 43, the digital waveform data of a designated number of horizontal scanning lines as counted from a predetermined horizontal scanning line of the CCD 22 are stored. The waveform data stored in the RAM 43 are read into a processor 50 through an address bus A-BUS and a data bus D-BUS controlled by the process 50 and are subjected to predetermined waveform processing. To the address bus A-BUS and data bus D-BUS of the processor 50, a stage controller 52 is connected to control the stage ST. This controller 52 receives the coordinate measurement values from the interferometers IFX and IFY and controls a driving motor 54 of the stage ST.

Next, with reference to FIG. 4, FIG. 5, and FIG. 6, the mark configuration and arrangement suitable for the present embodiment will be described.

FIG. 4 shows the shot arrangement on the wafer W, and the projected image in the pattern area PA of the reticle R is aligned with respect to each of the shot areas SA. Then, during the exposure, the center CC of each of the shot areas SA coincides with the center of the pattern area PA of the reticle R. The center lines rectangular at the center CC are parallel to the X and Y axes of the orthogonal coordinate system defined by the interferometers of the wafer stage ST.

Now, in each of the shot areas SA, the wafer marks for the die-by-die alignment MD1, MD2, MD3, and MD4 are formed. In the present embodiment, it will be assumed that these marks MD1 to MD4 are detected by the off-axis wafer alignment sensors (10 to 30). It will be also assumed that each of the marks MDn is a multi-mark composed of four bar marks BPM1, BPM2, BPM3, and BPM4 arranged in parallel with equal intervals as shown in FIG. 6(A). In addition, it will be assumed that as shown in FIG. 6(B), the bar marks BPMn are formed convexly on the wafer substrate. The center Cl of the mark MDn is located between the bar marks BPM2 and BPM3.

In addition, FIG. 5 shows the arrangement of the index marks TL and TR on the conjugate index plate 18, and each of the index marks TL and TR is formed by two fine lines which are formed by a chrome layer on a transparent glass plate. During the alignment, the stage ST is positioned so that the mark MDn is interposed between the two index marks TL and TR. FIG. 7 shows an example of the video signal waveform thus obtained.

FIG. 7(A) shows the state where the wafer mark MDn is interposed between the index marks TL and TR, and there is a slight deviation between the center Cl of the wafer mark MDn and the center Ct of the index marks TL and TR. The processor 50 shown in FIG. 3 computes this deviation amount precisely. As shown in FIG. 7(B), the video signal waveform obtained along the horizontal scanning line SL of the CCD 22 becomes bottom (minimum value) only at the edge positions of each mark because the interference phenomenon on the resist layer is reduced by the use of the wideband illumination light. In FIG. 7(B), the index marks TL and TR each are composed of two fine bar marks. Accordingly, one bar mark thereof has one bottom waveform, and thus BL1, BL2, BR1, and BR2 are obtained. Moreover, at each of the edge positions of the four bar marks BPM1 to BPM4 of the wafer mark MDn, a total of eight bottom waveforms WL1, WR1, WL2, WR2, WL3, WR3, WL4, and WR4 are obtained.

Nevertheless, the optical phenomena of the bottom waveforms appearing at the positions of the index marks TL and TR and the bottom waveforms appearing at the respective edge positions of the wafer mark MDn are completely different. In

other words, the index marks TL and TR are imaged on the CCD 22 as dark portions because they are illuminated by the transmission of the illumination light reflected from the wafer surface. On the contrary, the edges of the wafer mark are imaged as dark portions (dark lines) because the illumination light is scattered at an angle larger than the numerical aperture (NA) of the objective lens 12 or the like and will not return in the imaging optical path to the CCD 22.

In this respect, the signal waveform shown in FIG. 7(B) is the one obtained by averaging the signal waveform obtained along N scanning lines SL by the number of pixel columns in the vertical direction as shown in FIG. 7(A). This averaging is executed by the processor 50 reading the waveform data for N lines from the RAM 43.

Subsequently, the alignment method according to the present embodiment will be described. In this description, it will be assumed that several parameters are set in the processor 50 in advance. The typical parameters thereof are given below.

(1) A center address value ACC for the index marks TL and TR

(2) A distance Lt (μm) between the index marks TL and TR on the wafer

(3) Respective number Kt of index marks TL and TR

(4) Number Km of wafer marks MDn

(5) Point (address) numbers HL and HR from the center address value ACC of the index marks TL and TR

(6) Point (address) numbers Pt for each processing width of the index marks TL and TR

(7) Point (address) numbers Pm of the processing width from the center address value ACC of the wafer marks MDn

Of these parameters, the meanings of the point numbers HL, HR, Pt, and Pm are illustrated in FIG. 7(A).

In addition, in the present embodiment, it will be assumed that after completion of global alignment of the wafer W, fine positional detection is performed by the use of the wafer alignment sensors. Therefore, if the index marks TL and TR and the wafer mark MDn are detected by positioning the stage ST based on only the designed value of the shot arrangement on the wafer W after the global alignment is completed, there will be an alignment error ΔX corresponding to the residual error (±1 μm or less) during the global alignment, including small irregularities of the shot arrangement or the expansion/contraction of the wafer (W). This alignment error ΔX is the difference between the central positions Cl and Ct shown in FIG. 7.

Meanwhile, when the waveform data for N scanning lines imaged by the CCD 22 are loaded into the RAM 43, the processor 50 executes the waveform processing according to the procedure shown in FIG. 8. Hereinafter, the processing will be described along the steps shown in FIG. 8.

Step 100

In this step, data for an arbitrary number of lines are selected from the original waveform data for N lines which have been loaded into the RAM 43, and are averaged for each pixel in the vertical direction to produce averaged waveform data for one line. The averaged waveform data thus produced is temporarily stored in the RAM 43.

In this respect, the scanning lines to be subjected to the averaging are not necessarily continuous in the vertical direction but may be selected at intervals of one line or two lines.

Step 102

Subsequently, the processor 50 executes smoothing of the averaged waveform data. This smoothing is carried out by passing the averaged waveform data through a numerical filter.

FIG. 9(A) shows an example of the averaged waveform data in the RAM 43, and the horizontal axis represents the address point of the RAM 43 and the vertical axis represents the level. This waveform is passed through a numerical filter FNa as shown in FIG. 9(B). In this way, the high-frequency components existing in the averaged waveform data are removed, and smoothed waveform data R(n) can be obtained. This waveform data R(n) is also temporarily stored in the RAM 43.

Step 104

Then, the processor 50 differentiates the averaged waveform data. This differentiation is carried out by passing the averaged waveform data through a numerical filter FNb having a constant inclination as shown in FIG. 9(C). In this way, the bottom waveform as shown in FIG. 9(A) becomes such differentiated waveform data P(n) as shown in FIG. 9(D). The address point PXD which is the bottom point on this differentiated waveform data coincides with the intermediate position of the down-slope portion DWS on the averaged waveform data (or smoothed waveform data), and the address point PXU which is the peak point on the differentiated waveform data coincides with the intermediate position of the up-slope portion UPS in the averaged waveform data.

Therefore, by executing the differentiation process, all slope positions on the smoothed waveform data can be defined. In this respect, the zero-crossing point for the differentiated waveform between the address points PXD and PXU in FIG. 9(D) coincides with the bottom point in the waveform shown in FIG. 9(A).

Step 106

Next, the processor 50 extracts all peak and bottom points in this differentiated waveform data P(n) and the positions thereof. In this case, as shown in FIG. 9(D), small bottoms and peaks Dub and Dup other than the original bottoms and peaks may also be extracted.

Step 108

Then, the processor 50 discards these small bottoms and peaks Dub and Dup in order of size (smaller first), and selects the bottom points and peak points in numbers corresponding to the number Kt of index marks and the number Km of wafer marks.

As shown in FIG. 7 earlier, within the waveform processing width Pt corresponding to the left and right index marks TL and TR, it is known that two bottom waveforms are obtainable on the smoothed waveform data R(n) (index mark number Kt=2). Therefore, within the processing width Pt, two peak points and two bottom points can be obtained on the differentiated waveform data P(n).

On the other hand, within the processing width 2Pm corresponding to the wafer mark MDn, it is known that eight (2Km) bottom waveforms are obtainable on the smoothed waveform data R(n). Therefore, within the processing width 2Pm, the eight peak points and eight bottom points can be obtained on the differentiated waveform data P(n).

With the processing set forth above, the down-slope portions and up-slope portions corresponding to the marks on the smoothed waveform data are defined.

FIG. 10 represents such states, in which FIG. 10(A) shows the smoothed waveform data, and FIG. 10(B) shows the differentiated waveform data. Here, the horizontal axis in FIG. 10 represents the address points of the smoothed waveform data, and the central positions of the respective slopes in the smoothed waveform data are calculated so as to correspond to the peak points and bottom points on the differentiated waveform data.

The central positions of the respective slopes on the smoothed waveforms (BL1 and BL2) corresponding to the left index mark TL are two down-slopes RD(1) and RD(2) and two up-slopes RU(1) and RU(2). In addition, the central positions of the respective slopes on the smoothed waveform (BR1 and BR2) corresponding to the right index mark TR are two down-slopes RD(3) and RD(4) and two up-slopes RU(3) and RU(4).

Likewise, the central positions of the respective slopes on the smoothed waveforms generated at the respective edges of the four bar marks BPM1 to BPM2 are down-slopes WD(1) to WD(8) and up-slopes WU(1) to WU(8).

Here, as a method of defining the down-slope and up-slope, it is practically desirable to establish a contrast limit by using the respective contrast values (levels) of the smoothed waveforms and differentiated waveforms and then define the respective slope positions in the smoothed waveforms based on the limit value.

FIG. 11(A) is an enlarged view of only the bottom waveform WL1 in those shown in FIG. 10(A), and FIG. 11(B) is an enlarged view of only the differentiated waveforms in FIG. 11(A).

At first, the absolute value of the differentiated level (contrast value) CWD(1) corresponding to the bottom position WD(1) in the differentiated waveform data is obtained. Then, the level CDS(1) in the smoothed waveform corresponding to the position WD(1) is obtained. This level CDS(1) is registered as a value slightly smaller than the level in the down-slope defined by the position CWD(1).

Subsequently, the processor calculates the contrast value CVW(1) by an equation given below.

$CVWd(1)=A\cdot CDS(1)+B\cdot CWD(1)$

Likewise, the absolute value of the differentiated level CWU(1) corresponding to the peak position WU(1) in the differentiated waveform data is obtained. Then, the level CUS(1) in the smoothed waveform corresponding to the position WU(1) is further obtained.

Subsequently, the contrast value CVWu(1) is calculated by an equation given below.

$CVWu(1)=A\cdot CUS(1)+B\cdot CWU(1)$

Here, A and B are constant, and if noise should be separated, they are approximately set as A=1 and B=0.5.

The above-mentioned operations are executed within the signal processing range for the wafer mark, and exactly the same operations are executed for the signal waveform of the index mark.

As for the index mark, for example, the bottom waveform BL1 in FIG. 10(A) has its bottom position at RD(1) and peak position at RU(1) in the differentiated waveform.

Then, assuming that the level (bottom) in the differentiated waveform at the position RD(1) is CFD(1); the level (peak) in the differentiated waveform at the position RU(1) is CFU(1); the level in the vicinity of the center of the down-slope of the bottom waveform BL1 in the smoothed waveform is CDR(1); and the level in the vicinity of the up-slope is CUR(1), the contrast values CVRd(1) and CVRu(1) of the index mark are obtained, respectively as follows:

$CVRd(1)=A\cdot CDR(1)+B\cdot CFD(1)$

$CVRu(1)=A\cdot CUR(1)+B\cdot CFU(1)$

Then, the processor obtains the contrast ratio GG of the wafer mark to the index mark by an equation given below.

$GG=CVWd(1)/CVRd(1)\times 100(\%)$; or

$GG=CVWu(1)/CVRu(1)\times 100(\%)$

Then, if this contrast ratio GG is equal to or smaller than a predetermined ratio, the processor determines that the bottom waveform is not the one which corresponds to the edge of the wafer mark.

<u>Step 110</u>

Subsequently, the processor 50 compares the respective slope portions in the smoothed waveform with a predetermined slice level to obtain its intersections. This step 110 may be omitted in some cases because sometimes it is possible to use the central positions of the respective slopes on the smoothed waveform obtained as shown in FIG. 10 in the subsequent processes.

In this step 110, the optimum slice level is determined for each of the slopes as described earlier in conjunction with FIG. 2(C). When this slice level is determined, the up-slope positions RU(1) to RU(4) and down-slope positions RD(1) to RD(4) of the index mark obtained earlier in FIG. 10 and the up-slope positions WU(1) to WU(8) and down-slope positions WD(1) to WD(8) of the wafer mark are used. Now, a specific example will be described with reference to FIG. 12. First, as shown in FIG. 12(A), the waveform data corresponding to a predetermined number of points (addresses) are searched in portions before and after the down slope position WD(1) of one bottom waveform WL1 on the smoothed waveform. Then, the minimum value BT of the bottom of the down-slope and the maximum value SPd of the shoulder of the down-slope are obtained, and as shown in FIG. 12(B), the slice level S1 is defined at a location where the values between the minimum value BT and the maximum value SPd are divided by the predetermined ratio.

Here, assuming that the ratio thereof is $\alpha$(%), the slice level S1 is calculated by an equation given below.

$$S1=(SPd-BT)\times(\alpha/100)+BT$$

Subsequently, the position of the level of the down-slope portion which coincides with this slice level S1 is obtained. At this time, if the level which coincides with the slice level S1 exists between the sampling points, the intersecting point SWD(1) is obtained by a method of linear interpolation or the like. This position SWD(1) is, for example, represented by a real number which is obtained by interpolating the space between the address points with 1/10.

In the same way as above, a search is carried out in portions before and after the position WU(1) for the up-slope of the bottom waveform WL1 on the smoothed waveform (here, since the minimum value BT is known, the search may be performed in only one direction), and the slice level S2 is defined by an equation given below.

$$S2=(SPu-BT)\times(\alpha/100)+BT$$

Then, the position SWU(1) of the up-slope portion which coincides with this slice level S2 is calculated as a real number.

Thereafter, the optimum slice levels for each of the bottom waveforms in the smoothed waveform are defined in the same fashion to obtain the intersecting points SRU(1) to SRU(4), SRD(1) to SRD(4), SWU(1) to SWU(8), and SWD(1) to SWD(8).

Step 112

Next, the processor 50 examines one pixel of the CCD 22 (the sampling space of the smoothed waveform data) to calculate its length in terms of μm on the surface of the wafer in order to cancel any magnification error and the like of the optical system of the wafer alignment sensor, and obtains the converted value UNT thereof (μm/point) as a real number. Here, it will be assumed that a designed space Lt (μm) of the index marks TL and TR having excellent stability is used. Since the space Lt is registered as a value on the wafer surface, the converted value UNT is calculated by an equation given below. In this respect, both index marks TL and TR are assumed to have Lt lines (in the present embodiment, Kt=2).

$$UNT = \frac{2Kt \cdot Lt}{\sum_{n=Kt+1}^{2Kt} \{SRU(n)+SRD(n)\} - \sum_{n=1}^{Kt} \{SRU(n)+SRD(n)\}}$$

Step 114

Subsequently, the processor 50 obtains the central position Ct (μm) between the index marks TL and TR as a real number in accordance with an equation given below.

$$Ct = \frac{\sum_{n=1}^{2Kt} \{SRU(n)+SRD(n)\}}{4Kt} \times UNT$$

Step 116

In this step, an algorithm for calculating the central position Cl of the wafer mark is selected in accordance with the processing mode designated in advance. The process (either one of the steps 118, 120, and 122) that will be performed subsequently to the step 116 is designated by an operator or is automatically switched by an auto-set-up system.

Step 118

In this step, the central position Cl (μm) of the wafer mark is calculated as a real number by the inner slope detection method.

Here, with reference to FIG. 10 described earlier, the inner slope positions on the wafer mark waveform are SWU(1), SWD(2), SWU(3), SWD(4), SWU(5), SWD(6), SWU(7), and SWD(8).

Therefore, the number of wafer marks is assumed as Km (in the present embodiment, Km=4), and the central position Cl is calculated in accordance with an equation given below.

$$Cl=\frac{\sum_{n=1}^{2Km}\left[\frac{1-(-1)^n}{2}\cdot\{SWU(n)+SWD(n+1)\}\right]}{2Km}\times UNT$$

Step 120

In this step, the central position Cl (μm) of the wafer mark is calculated as a real number by the outer slope detection method.

Here, with reference to FIG. 10 described earlier, the outer slope positions of the wafer mark are SWD(1), SWU(2), SWD(3), SWU(4), SWD(5), SWU(6), SWD(7), and SWU(8).

Therefore, the central position Cl is calculated here in accordance with an equation given below.

$$Cl=\frac{\sum_{n=1}^{2Km}\left[\frac{1-(-1)^n}{2}\cdot\{SWD(n)+SWU(n+1)\}\right]}{2Km}\times UNT$$

Step 122

In this step, the central position Cl (μm) of the wafer mark is calculated as a real number by the both-slope detection method.

As is clear from FIG. 10 described earlier, the average position of all down-slopes and up-slopes on the wafer mark waveform becomes the center Cl. Therefore the central position Cl is calculated in accordance with an equation given below.

$$Cl=\frac{\sum_{n=1}^{2Km}\{SWD(n)+SWU(n)\}}{4Km}\times UNT$$

Step 124

Subsequently, the processor 50 determines the alignment error ΔA (μm) by computing the difference between the central position Ct of the index mark and the central position Cl of the wafer mark.

This alignment error ΔA is the residual alignment error of the wafer stage ST when the video signal waveform was loaded into the RAM 43. Therefore, in positioning of the stage ST thereafter, it may be helpful to offset the designed value of the stage positioning coordinate defined by the global alignment by only ΔA.

Hereinabove, the basic alignment procedure of the present embodiment has been described. Now, an example will be described as to the selection of the processing mode at the step 116 according to the present embodiment.

Usually, the processes for forming devices on a semiconductor wafer include a process of depositing an aluminum layer uniformly thereon to produce wirings between the devices. A concavo-convex alignment mark on the wafer is detected by an alignment sensor in such a state where the mark is covered with the aluminum layer. In other words, the mark which is formed as the aluminum layer is detected.

As a result, if the aluminum layer is not uniformly deposited on the mark and becomes asymmetrical, the video signal waveform (bottom waveform) corresponding to the edge portion at both ends of the mark also becomes asymmetrical. FIG. 13(A) shows the sectional structure of the alignment mark WM covered by the aluminum layer Al. The mark image, which has been imaged by the CCD 22 and projected on the television monitor, as shown in FIG. 13(B), has dark lines which appear on the left and right edge portions and have different widths.

This is due to the fact that the aluminum layer Al is deposited asymmetrically at the left and right edge portions of the mark WM as shown in FIG. 13(A). When this mark WM is observed by the use of visible band illumination light, only the surface of the aluminum layer Al will be visible. Accordingly, the video signal waveform output by the CCD 22 becomes as shown in FIG. 13(C), and the bottom waveforms corresponding to the left and right edge portions also become different from each other.

When the signal waveform processing algorithm of the present embodiment is applied to such a waveform to obtain the outer slope positions SWD(1) and SWU(2) and the inner slope positions SWU(1) and SWD(2), and the both-slope detection method is selected at the step 122 shown in FIG. 8, the central position Cl of the mark WM shown in FIG. 13 is obtained by an equation given below.

$$Cl=\{SWD(1)+SWD(2)+SWU(1)+SWD(2)\}/4$$

Nevertheless, it was ascertained by experiments that even when a mark with such a strong asymmetry was detected by the both-slope detection method and alignment is performed, the resultant precision was not necessarily sufficient.

One reason for this is that there is a problem using a vernier to examine the alignment (overlay) precision.

In examining the overlay precision with the vernier, the auxiliary scale of the vernier on the reticle is positioned with respect to the vernier main scale formed in advance on the wafer by the use of the alignment sensor to produce an overprint. Then, the alignment precision is determined by reading the amount of deviation of the vernier produced by the overprint.

Conventionally, this examination is carried out in such a manner that after the overprinted wafer is developed using a stepper, the auxiliary scale of the vernier formed by the resist and the vernier main scale on the substrate are observed by

different optical microscopes or the like to read the amount of deviation of the vernier by eye-sight.

FIGS. 14(A) and 14(B) and FIGS. 15(A) and 15(B) show examples of the vernier on the aluminum layer. FIGS. 14(A) and 14(B) show the case where the vernier auxiliary scale WBS is penetratingly formed in the resist layer PR over the vernier main scale WBM. FIGS. 15(A) and 15(B) show the case where two vernier auxiliary scales WBS are penetratingly formed in the resist layer PR on both sides of the vernier main scale WBM.

Here, the vernier main scale WBM is assumed to be asymmetric.

When these verniers are measured by eye-sight, the distances a and b between the edge portions of the auxiliary scale WBS on the resist and the adjacent edge portions of the main scale are read, and the position where these distances are the same by eye-sight is regarded as indicating the alignment precision.

Specifically, as shown in FIG. 16, the main scales WBM are produced at constant pitches in the measuring direction, and the auxiliary scales WBS to be overprinted thereon are provided at pitches larger than those of the main scales WBM by 0.02 μm, for example. If the alignment is performed ideally, the centers of the main scales WBM and the auxiliary scales WBS will be overlapped with each other at the position represented by a numeral 0 printed on the vernier. In the case shown in FIG. 16, the centers of the main scales WBM and the auxiliary scales WBS are overlapped at the position represented by a numeral -0.2. Hence, the alignment precision obtained is -0.02 μm. Although FIG. 16 shows the vernier patterns of the method shown in FIG. 14, the same is applicable to the method shown in FIG. 15.

In the case of the vernier type shown in FIG. 14, the edge positions on the main scale WBM which defines the distances a and b are the outer slope positions SWU(1) and SWD(2) if these edges were located on the waveform shown in FIG. 13(C).

On the other hand, with the vernier type shown in FIG. 15, the edge positions on the main scale WBM which defines the distances a and b are the outer slope positions SWD(1) and SWU(2) if these edges were located on the waveform shown in FIG. 13(C).

In other words, when the actual alignment is performed, it is necessary to select the outer slope detection method or the inner slope detection method depending on the vernier type that has been used for checking the alignment precision.

Therefore, it may be helpful to select the inner slope detection method (the step 118 in FIG. 8) in the case of checking the alignment with the vernier type shown in FIG. 14 (FIG. 16) and select the outer slope detection method (the step 120 in FIG. 8) for the vernier type shown in FIG. 15.

In this way, the alignment precision measured by the vernier scale with eye-sight can be accurately coordinated with the alignment error detected by the wafer alignment sensor.

However, depending on processes, the alignment may sometimes be performed with respect to the mark WM under the aluminum layer Al. In such a case, it is difficult to define the degree of asymmetry of the aluminum layer Al formed on the mark WM. Therefore, subsequent to the verification of the asymmetry thereof by examining the sectional structure of the mark, an automatic selection should be arranged to provide more weight on the inner slope detection method or on the outer slope detection method in accordance with the degree of the asymmetry thus verified. For example, the central position of the mark Cl for a single mark waveform such as shown in FIG. 13(C) is determined by an equation given below.

$$Cl = \frac{A\{SWD(1) + SWU(2)\} + B\{SWU(1) + SWD(2)\}}{2(A + B)}$$

This equation is a modification of the equation for the both-slope detection method with the insertion of the weighting constants A and B, and the constants A and B only need to satisfy the conditions given below.

$0<A<2$, $0<B<2$, $A+B=2$

Here, if both weighting constants A and B are given as 1, then the related equation is for the both-slope detection method.

In this respect, as a method of examining the sectional structure of the mark, there is considered a method using a scanning electron microscope (SEM) measuring machine or an ultrasonic microscope, or a method such as applying an optical measurement by the use of an infrared laser spot or illumination light capable of transmitting itself through the aluminum layer Al.

Now, the asymmetry of the aluminum layer Al, when it is deposited, tends to expand isotropically from the center of the wafer, and it is possible to recognize the asymmetry as shown in FIG. 17, for example, at the position where the shot (chip) marks positioned at the periphery of the wafer surface are observed by eye-sight through the wafer alignment sensor.

FIG. 17 shows the four shot positions at the periphery on the shot arrangement coordinate XY with the wafer center as its substantial home position. For each shot, the marks, respectively for the X direction alignment and Y direction alignment are provided. For the two shots positioned apart from each other in the Y axis direction on the coordinate XY, the mark MDy for the Y direction alignment is observed. For the two shots apart from each other in the X axis direction, the mark MDx for the X direction alignment is observed.

At this time, the signal waveform of each mark imaged by the CCD 22 is processed to obtain the width of the bottom waveform at the mark edge portions, i.e., the difference between the positions SWD(1) and SWU(1) shown in FIG. 13(C), and the difference between the positions SWD(2) and SWU(2). Hence, it becomes clear that there is a strong asymmetry on the edge having the larger difference. The amount of this asymmetry AU is obtainable by an equation given below.

$$\Delta U=\frac{\{SWD(1)+SWU(2)\}-\{SWU(1)+SWD(2)\}}{2}$$

In this way, by detecting some of the shot marks on the periphery of the wafer and calculating the amounts of the asymmetry ΔU at those positions, it is possible to define the asymmetry during the aluminum layer deposition almost over the entire surface of the wafer.

Therefore, as shown in FIG. 1, in the stepper provided with the detection system for detecting the die-by-die mark on the reticle R and the mark for one shot on the wafer W with the TTR alignment system DAS1 to DAS4, it is possible to correct the wafer mark position aligned by the TTR alignment system in accordance with the asymmetry of the mark.

Here, as an example of the TTR alignment system, the interference alignment system disclosed in Japanese Unexamined Patent Application Publication No. S63-283129 is considered.

FIG. 18 is a diagram schematically showing an interference alignment system which is slightly different from the one disclosed in Japanese Unexamined Patent Application Publication No. S63-283129 but is identical in principle.

On the reticle R, diffraction gratings Gr1 and Gr2 are provided apart from each other in the grating pitch direction in two transparent windows as die-by-die marks, and two laser beams Lf1 and Lf2 having the wavelength different from the exposure light are diagonally irradiated onto the gratings Gr1 and Gr2, respectively. The major rays of the beams Lf1 and Lf2 intersect each other in the space above the reticle R, and the distance between the intersecting point and reticle R in the optical axis direction corresponds to the amount of the chromatic aberration on the axis of the projection lens in the wavelength of the beams Lf1 and Lf2. The beams Lf1 and Lf2 having been transmitted through the transversal transparent portions of the gratings Gr1 and Gr2 on the reticle R intersect each other on the wafer W through the projection lens. In the intersecting area, a one-dimensional interference fringe is produced in parallel with the diffraction grating Gw on the wafer W. From the grating Gw on the wafer W, the interfering light BTL generated by the interference of the ±1st-order diffracted light beams is generated vertically, and this interfering light BTL reversely propagates in the projection lens through the center of the transparent

window of the reticle R to be photoelectrically converted. Here, if a small frequency difference Δf is given to the two beams Lf1 and Lf2, the interference fringe formed on the grating Gw of the wafer W flows at a speed corresponding to the frequency difference Δf, and the photoelectrical signal (measuring signal) of the interfering light BTL becomes the alternating current signal which changes like a sine wave with the frequency Δf.

Meanwhile, from the grating Gr1 and Gr2 of the reticle R, the ±1st-order diffracted light beams DL1 and DL2 are generated in the opposite direction to the transmitted light beams Lf1 and Lf2, and the reference signal is produced by photoelectrically detecting the interfering light generated by the interference of the ±1st-order diffracted light beams DL1 and DL2.

This reference signal also becomes the alternating current signal which changes like the sine wave with the frequency Δf, and the phase difference Δϕ (within ±180°) between the reference signal and the measuring signal corresponds to the amount of deviation in the pitch direction between the gratings Gr1 and Gr2 of the reticle R and the grating Gw of the wafer W. The system in which the frequency difference Δf is given to the two beams Lf1 and Lf2 is specifically called the heterodyne interference alignment system. According to this system, when the pitch of the grating Gw is set to approximately 4 μm (line-and-space width of 2 μm), since the maximum phase difference ±180° corresponds to ±1 μm, it is possible to obtain a phase difference measuring resolution of ±2° and thus detect a positional deviation of approximately ±0.01 μm.

When a high-precision, high-resolution TTR alignment sensor is used, if each of the grating elements of the grating mark Gw on the wafer W has asymmetry, it goes without saying that errors (offset) will be included in the resultant mark position detection. Subsequently, therefore, a method of offset correction will be described, in which the asymmetry of the mark presenting a problem in a TTR alignment system of this kind is estimated by the wafer alignment sensor using wideband illumination light, thus correcting the offset.

FIG. 19(A) shows the sectional shape of the grating mark Gw on the wafer W, and the edge on the right side of each of the grating elements is deformed. Therefore, even if the TTR alignment system shown in FIG. 18 is used to perform the alignment with the gratings Gr1 and Gr2 on the reticle R by flowing the interference fringe IF to detect the grating mark Gw with the heterodyne detection, an offset may remain such as that obtained by averaging the amounts of the asymmetry of the individual grating elements.

Therefore, in the same way as the embodiment described earlier, the grating mark Gw is imaged by the CCD 22. At that time, the horizontal scanning direction of the CCD is arranged to be in parallel with the pitch direction of the grating mark Gw.

Thus, as shown in FIG. 19(B), the video signal waveform from the CCD 22 becomes the bottom waveform asymmetrical at the edge portions of both sides of each grating element. Then, as described in conjunction with FIG. 13, the down-slope position SWD(n) and up-slope position SWU(n) are obtained. Moreover, when the amount of asymmetry AU(n) is calculated for each of the grating elements and is averaged, the amount of the asymmetry as a whole is obtained for the grating mark Gw. Therefore, during the die-by-die alignment, if the alignment is performed by the TTR alignment system in accordance with its resultant mark position detection and the offset based on this amount thus calculated, it is possible to reduce errors due to the asymmetry of the mark even when a TTR alignment system using a single wavelength illumination beam is employed.

Next, with reference to FIG. 20, the description will be made of the case where the clear bottom waveform does not appear at the edge portions of the alignment mark due to the signal process algorithm.

FIG. 20(A) shows the case where the reflectance of the multi-mark MD (convex portion) on the wafer is extremely different from its peripheral reflectance. The signal waveform obtained at this time has the shape of a waveform corresponding to the contrast difference between the mark and the substrate.

FIG. 20(B) shows the case where the line and space duty of the multi-mark MD is set to a value other than 50%, and if the line width of the adjacent convex bar mark is narrow, the bottom waveform at the left and right edges is not separated and becomes a single bottom waveform.

In addition, FIG. 20(C) shows the case where each of the bar marks of the multi-mark MD is formed by a square dot to construct the grating. In this case, it is also impossible to obtain a clear bottom waveform. The waveform becomes a short form wave.

In either case of those shown in FIG. 20, the inner slope detection method cannot be utilized. Only the outer slope detection method is employed. As described in the embodiment earlier, the number of wafer mark lines Km is defined in advance as an operation of the algorithm, and it is assumed that the bottom waveform having a constant contrast on the signal waveform is obtained only for the number 2Km. As a result, an error tends to occur in the algorithm (operation) if the bottom waveform generated at the mark edge portions is not clear.

Therefore, a routine for judging the contrast is added to the flowchart shown in FIG. 8, so that the processing system automatically selects the step 120 in FIG. 8 if the signal waveform shows the state as shown in FIG. 20.

FIG. 21 is a flowchart showing an example of such contrast determining routine, which is executed in place of the step 116 shown in FIG. 8.

Hereinafter, each of the steps shown in FIG. 21 will be described.

Step 200

In this step, zero is set for the inner counter (software counter) FN of the processor. This counter FN is provided for discriminating the waveform shown in FIG. 20 from the normal waveform shown in FIG. 10.

Step 202

Here, the description will be made assuming that the waveform shown in FIG. 22 was obtained.

At first, since the down-slope position SWD(n) or WD(n) has been obtained in the waveform shown in FIG. 22, the contrast values (levels) CVl and CVr each at a predetermined distance to the left and right therefrom are obtained. The predetermined distance is set to be substantially equal to or slightly longer than the width of the normal bottom waveform at the edge.

Step 204

Subsequently, the processor calculates the difference between the contrast values CVl and CVr, and determines whether or not the difference is larger than a predetermined value GC.

The first bottom waveform in FIG. 22 is normal, corresponding to only the mark edge portion. Accordingly, the difference between the contrast values CVl and CVr is not so large, and the process proceeds to the step 206.

Step 206

In this step, the content of the counter FN is incremented by +1.

Step 208

The processor determines whether or not all down-slope positions SWD(n) have been checked, and if the check has not been completed, the processor instructs a jump to the step 202 to execute the same process for the next down-slope.

Step 210

In this step, the processor determines whether or not the content of the counter FN still remains zero. The counter FN is not incremented in a state such as the down-slope position SWD(2) in FIG. 22, i.e., when the difference between the contrast value CVl and CVr before and after the position SWD(2) is greater than the value GC. Consequently, if the counter FN is zero, it means that the signal waveform is in the condition shown in FIG. 20, and the processor executes automatically (forcibly) the step 120 to perform the outer slope detection.

Step 212

In addition, if the counter FN is not zero, the processor compares the counted value with the wafer mark line number Km, and determines that the signal waveform is in the condition shown in FIG. 22 if the value and the number do not coincide. Then, the step 118 is executed to perform the inner slope detection.

Moreover, if the value of the counter FN coincides with the mark number Km, the processor determines that the normal bottom waveform has been generated with respect to all the mark edge portions, and executes a processing mode (either one of the three slope detection methods) designated in advance by the user (operator).

By the operations described above, even when the signal waveform as shown in FIG. 20 is obtained, the process can be executed without errors by the algorithm. Nevertheless, in the case of the mark shown in FIG. 20, only the outer slope detection method is useable. Therefore, even if the inner slope detection method is found to be optimum in consideration of the asymmetry based on the vernier configuration as described in conjunction with FIG. 14 and FIG. 15, it is impossible to deal with this. For example, in the case of a multi-mark having one narrow convex bar mark as shown in FIG. 20(C) or FIG. 20(B), there appears a conspicuous difference affected by the asymmetry based on the vernier configuration.

In such a case, therefore, it is possible to utilize an optimum slope detection method determined by the vernier configuration by replacing the convex bar mark with a concave bar mark.

In this respect, if the multi-mark composed of lines and spaces as shown in FIG. 20(B) earlier is used, only one bottom waveform is generated for one bar mark. The arrangement can be made so as to obtain the bottom waveform which is separated at the edges at both sides of one bar mark while changing the duty ratio of the line-and-space. This method is effectively applicable to the wafer grating Gw of the interference alignment system shown in FIG. 19. In the interference alignment system, the narrower the pitch of the grating mark Gw, the higher becomes its resolution. However, for the wafer alignment sensor using the CCD 22, as the pitch of the grating mark Gw decreases, the waveform of the video signal becomes such as shown in FIG. 20(A), and the contrast is further worsened. Therefore, by changing the duty ratio without changing the pitch of the grating mark Gw, it is possible to produce the waveform of the video signal as close as possible to the one shown in FIG. 19(B) or FIG. 20(B).

In the apparatus of the present embodiment, the illumination light for observing the wafer mark has a wideband, and there is no interference phenomenon due to the resist layer at all. Therefore, in order to increase the resolving power (magnification), the numerical aperture (NA) of the optical system (objective lens 12) before the CCD 22 may be decreased. However, it becomes impossible to obtain a practicable depth of focus. Therefore, the numerical aperture of the objective lens 12 is set to be approximately half that of the projection lens PL, NA=approximately 0.2 to 0.3, for example. Moreover, the total imaging magnification, which is determined by the optical system (12 and 16) from the wafer surface to the conjugate index plate 18 and the optical system (20) from the conjugate index plate 18 to the CCD 22, is set

to be approximately 30 to 50. By doing so, even when the line-and-space of the practicable multi-mark is set to be 4 μm (pitch 8 μm), no split top phenomenon will appear in the bottom waveform on the video signal waveform with respect to the mark edge portion. The split top phenomenon is a phenomenon in which when the cross-section of the convex bar mark shown in FIG. 23(A) is considered, each of the bottom edges (outer edges) BE1 and BE2 and the top edges (inner edges) TE1 and TE2 is separated to be the bottom waveforms BWB1, BWB2, BWT1, and BWT2 as shown in FIG. 23(B). This is caused by the fact that even when the illumination light IL is irradiated in the direction perpendicular to the edge taper portion between the bottom edge BE1 (BE2) and the top edge TE1 (TE2), the scattered rays of light DFL from the tapered portion will return to the CCD 22 if the numerical aperture of the objective lens 12 is large and its magnification is high.

Consequently, when the video signal shown in FIG. 23(B) is supplied to a television monitor and observed on its screen, the edge portions of the bar mark may appear as two fine black lines.

When the signal waveform with the split top phenomenon is processed, the separated bottom waveforms BWB1 and BWT1 may be sometimes erroneously recognized as two edges.

In the apparatus of the present embodiment, considering the experimental changes in the configuration of the wafer mark in the course of processes so as not to create such a split top phenomenon, the numerical aperture of the objective lens 12 is set to be comparatively as small as 0.2 to 0.3 and the magnification up to the CCD 22 is set to be comparatively as small as 30 to 50. Moreover, the cell size (cell pitch) of the CCD 22 is approximately 0.2 μm to 0.3 μm in terms of the wafer surface.

Subsequently, with reference to FIG. 24 and FIG. 25, the system configuration of a second embodiment according to the present invention will be described. In the present embodiment, the conjugate index plate 18, the structure of the CCD 22, and the method of the wafer mark alignment are different from those in the previous embodiment. FIG. 24 shows the system in the case where the mark in the X direction on the wafer W and the one in the Y direction thereon are detected through a common optical system The system is different from that shown in FIG. 1 in that two sets of index mark groups for alignment in the X direction and Y direction thereon are formed on the index plate 18; a beam splitter 21 is provided after the imaging lens system 20 to divide the imaging beam into two; and two CCDs 22X and 22Y are provided to receive the divided imaging beams, respectively. However, the two CCDs 22X and 22Y are set up so that the horizontal scanning directions thereof are at angles of 90° to each other as indicated by arrow.

In addition, as shown in FIG. 25, the conjugate index plate 18 is provided with an area VPBx including the index mark groups TLA, TRA, TLB, and TRB in the X

direction, a transparent area VPAx above them, and a mark VCMx for eye-sight. Likewise, in the Y direction, the index mark groups TLA, TRA, TLB, and TRB, and a mark CVMy for eye-sight are provided.

The CCD 22X has an imaging range which covers the areas VPAx and VPBx and the mark VCMx and does not shade the index marks TRA and TLA in the Y direction. The same is applicable to the CCD 22Y. In the present embodiment, the conjugate index plate 18 and the system up to the imaging lens system 20 are used in common both in the X and Y directions. Accordingly, the mirror 10 to observe the wafer surface and the objective lens 12 are arranged at one location only.

In this respect, if the alignment optical system for the X direction and Y direction is each arranged to be separated from the objective lens, the conjugate index plate 18 is also separated for the X direction use and Y direction use as a matter of course.

However, the inner index marks TLA and TRA among those conjugate index mark groups shown in FIG. 25 are produced so as to interpose a multi-mark having seven bar marks of each 4 μm wide at intervals of 4 μm space. Therefore, in a case of detecting a single mark, not multi-mark, or the like, the wafer surface below each of the index marks TRA and TLA inevitably becomes a prohibitive area for marks or patterns. In other words, the formation area for the wafer mark should be provided widely on the street line, which restricts device fabrications.

In the present embodiment, therefore, during the detection of a single mark for the X direction use, the arrangement is made to interpose the single mark between the index marks TRA and TRB on the right side of FIG. 25, and only the video waveform portion including the index marks TRA and TRB is processed.

In addition, for a wide mark, the index marks TLB and TRB may be used.

Specifically, as shown in FIG. 26, it may be helpful to interpose the single mark WD between the index marks TRA and TRB, select the waveform portions in the index mark processing ranges R-L and R-R given as parameters in advance and the waveform portion in the wafer mark processing range W-A between them from the averaged waveform obtained by averaging the video signals for n scanning lines, and form the signal waveform in the same way as in the first embodiment. In addition, in regard to the multi-mark, the whole of which is widened, as shown in FIG. 27, the index mark processing ranges R-L and R-R are set so as to use the outer index marks TLB and TRB, and the wafer mark processing range W-A is set so as to exclude the wafer mark waveform portion which is overlapped with the inner index marks TLA and TRA. The setting of these processing ranges is automatically executed by registering the mark configurations and dimensions to be used in advance.

In addition, there are some cases where the mark is overlapped with the index mark to be used depending on the configuration of the registered mark. It may be possible to avoid such overlapping with the index mark by intentionally shifting the specific wafer mark position in the X or Y direction (measuring direction) after the wafer global alignment is completed.

Next, a third embodiment will be described. Here, the description is made of the case where the wafer alignment sensor of the off-axis type shown in FIG. 1 is utilized for the wafer global alignment.

In general, a stepper of this kind is used to detect the orientation flat of a wafer to mechanically position the wafer (pre-alignment), and mount it on the stage ST. In such a state, however, a pre-alignment error of approximately 20 μm to 100 μm exists. The global alignment is a process to search the global alignment marks on the wafer taking the pre-alignment error into consideration and coordinate the actual shot arrangement with the designed shot arrangement within the error range of approximately ±1 μm. Therefore, when a CCD camera is used for the global alignment, there may be some cases where the global mark is not found in the imaging range of the CCD camera if the pre-alignment error is large even when the stage ST is positioned by the designed value.

Therefore, when the global alignment is carried out for the wafer W by imaging the wafer surface with the CCD camera, it is necessary to perform the global search to observe the wafer surface with the CCD and shift the wafer by a predetermined amount. For this purpose, the transparent area VPAx (or VPAy) of the index plate 18 shown in FIG. 25 is used. Since this area VPAx is positioned in advance at a predetermined location on the imaging surface for the CCD 22X, the positions and number of scanning lines for scanning the area VPAx are known in advance. In addition, the global mark WGM on the wafer should be formed within the street line SAL shown in FIG. 28.

This global mark WGM is formed with three grating type marks arranged in parallel along the Y direction in which the street line SAL extends, and the distance from the chip area CPA on the left side of the street line SAL to the first grating type mark is a, while the distance from the chip area CPA on the right side to the third grating type mark is d. Moreover, the spaces between the three grating type marks are b and c, respectively.

Here, it will be assumed that as shown in FIG. 28, since the transparent area VPAx of the index plate 18 is placed mainly over the left chip area CPA when the wafer stage ST is initially positioned in accordance with the designed value, the first and second columns of the global mark WGM are obtained. At this time, if the video signals corresponding to a plurality of scanning lines within the area VPAx are averaged, the waveform data as shown in FIG. 29(A) are stored in the memory.

Subsequently, the waveform data initially stored are analyzed to verify whether they are for the global mark WGA or not. As an algorithm for such verification, the method disclosed in Japanese Unexamined Patent Application Publication No. S60-114914 is applicable, for example.

In other words, the waveform position which is the closest to the state of the designed arrangement relationship (spaces a, b, c, and d) of the mark WGM shown in FIG. 28 is searched.

Usually, three columns of the mark WGM are included in the waveform data initially stored as in FIG. 29(A). However, if the pre-alignment error is extremely large, the area VPAx does not cover the three columns of the mark WGM as shown in FIG. 28.

Thus, the processor shifts the wafer stage ST in the X direction by a predetermined amount and then stores the video signal waveform from the CCD camera in the memory. At this time, the area VPAx is shifted to the right side of FIG. 28 to overlap partially with the initial portion. The averaged waveform of the video signals obtained from the area VPAx which has been shifted to the right side becomes like that shown in FIG. 29(B). In FIG. 29, the overlapping range in the X direction of the area VPAx is DBA, and although this length can be accurately set by the interferometer IFX of the stage ST, it is desirable to define the range DBA to be slightly larger than the width (approximately b+c) of the mark WGA in the X direction.

Next, the processor compares the contrast value CVa of the overlapping range DBA of the video signal waveform which has been stored for the first time with the contrast value CVb of the overlapping region DBA of the video signal waveform which is stored for the second time.

In general, the CCD camera causes its AGC (auto-gain control) to operate when the average luminance on the screen changes. Therefore, in the overlapping range DBA, the contrast values CVa and CVb of the two waveform portions may change.

Therefore, if the two contrast values CVa and CVb differ greatly, the gain of either one of the first and second video signal waveforms is compensated by computation so that they are approximately equal to each other. Then, the two video signal waveforms are averaged to be connected together in the overlapping region DBA. This process is executed by the processor operating the data stored in the memory.

Thus, when the video signal waveforms are connected together by shifting the area VPAx relatively in the X direction, successive video signal waveforms from the region which is far wider than one screen of the CCD camera are stored in the

memory. Accordingly, it is possible to find the global mark WGM within the street line SAL based on the design rule (spaces a, b, c, and d).

As described above, the search of the global mark WGM is completed when the three columns of the mark are recognized. Then, the processing proceeds to the global fine alignment. The global fine alignment has several modifications, which can be roughly classified into a system that uses the wafer alignment sensor with the CCD camera employed for the present embodiment, and a system that uses the alignment sensor which is separately provided for the fine alignment.

In the case where the wafer alignment sensor with the CCD camera is utilized, the wafer stage ST is moved to arrange the global mark WGM within the area VPBx (FIG. 25) of the index plate 18 and the video signal waveform is obtained. Then, the alignment is precisely carried out by interposition of the index marks TLA and TRA or interposition of the second column (single mark) of the mark WGM between the index marks TRA and TRB.

In addition, in the case of using the fine global sensor which is separately provided, only the second column of the mark WGM is immediately detected, and the coordinate value of the stage ST at which the detected center of the sensor and the center of the second column of the mark coincide with each other should be measured.

Subsequently, a fourth embodiment will be described. Here, the description will be made of the case where the wafer alignment sensor of the off-axis type shown in FIG. 1 is utilized for EGA (enhanced global alignment).

Since the details of the EDA are disclosed in Japanese Unexamined Patent Application Publication No. S61-044429 or S62-0084516, description of the detailed calculation method thereof will be omitted.

FIG. 30 shows only the shots S1 to S8 which are subjected to sample alignment by the EGA system among the shot arrangement on the wafer. In the past, in the EGA system, the sample alignment of the shots S1 to S8 is executed subsequent to the completion of the global alignments in the X, Y, and θ directions, which is the prerequisite of this system.

In the present embodiment, the global alignment function in the θ direction is included in the EGA sequence to improve its throughput. In the general EGA, the marks in the X direction and Y direction for each shot are detected one after another in the order of the shots S1 to S8 to measure the central coordinate value of each shot. In the present embodiment, however, as for the first two shots, the sample alignment is performed for those having substantially the point symmetry on the wafer. Specifically, those two are the shots S3 and S7 aligned in the X direction or shots S1 and S5 aligned in the Y direction in FIG. 30.

Then, when the sample alignment has been completed for the two shots, the rotation amount Δθ for the XY coordinate system for the wafer (shot arrangement) as

a whole is calculated. Then, if this rotation amount $\Delta\theta$ is so large that it may lower the precision of the overall alignment in the EGA system, the wafer holder on the wafer stage ST should be rotated in the reverse direction finely by the amount $\Delta\theta$.

Subsequently, two shots are again subjected to the sample alignment, and if it was verified that the rotation amount $\Delta\theta$ was sufficiently small, then, the sample alignment is performed for the remaining shots and the EGA operation is performed.

In the above-mentioned sample alignment, the wafer alignment sensor shown in FIG. 1 and others is used to image the multi-mark with the wideband illumination light. Therefore, there is no interference phenomenon due to the resist layer, and it is possible to carry out a stable measurement of the mark positions. In the mark position measurements, at the same time that the amounts of deviation $\Delta x$ and $\Delta y$ between the center Ct of the index marks TL and TR and the center Cl of the wafer mark are obtained, the stop coordinate measurement value of the stage ST at that time should be read from the interferometers IFX and IFY for the storage.

As set forth above, in each of the embodiments according to the present invention, the description has been made mainly of the utilization of the alignment sensor for detecting the mark image using the wideband illumination light in consideration of the influence of the resist layer on the wafer. In recent years, however, there has been proposed a method that removes the resist layer only for the wafer mark portions. In this case, it is unnecessary to provide wideband mark illumination light, and an alignment sensor using an illumination light of single wavelength such as laser light can possibly be employed. The present invention is equally applicable to the case where the waveform of the video signal or photoelectrical signal obtained by the alignment sensor using the illumination light of such single wave length is analyzed. In such a case, if the resist layer for the mark portions has been removed, the waveform becomes a simple waveform such as having its bottom (or peak) at the mark edge as shown in each of the embodiments, and it is equally possible to deal with the effect of the asymmetry of the mark.

Effect of the Invention

As described above, according to the alignment method of the present invention, since the up-slope positions and the down-slope positions of the bottom portions in the mark signal waveform are used in a separate manner, it is possible to make the measurement precision for the mark central position identical to the overlay precision during actual device manufacturing. In addition, since it is possible to check the asymmetry of the bottom waveform in the mark waveform, it is possible to further improve the overlay precision of a layer (aluminum layer or the like) where the marks are likely to be deformed by the wafer processes.

In addition, the present invention can be equally applied to the alignment method employed for the SOR X-ray exposure apparatus, which has been in the process of development in recent years. However, since in the X-ray exposure, the mask and the wafer approach each other with a predetermined gap therebetween, it may be helpful to prepare an objective lens system having an additional double-focusing element so that the marks on the mask and the marks on the wafer can be detected simultaneously.

4. Brief Description of the Drawings

FIG. 1 is a perspective view showing the structure of a stepper suitable for implementing the method according to an embodiment of the present invention;

FIGS. 2(A) to 2(C) are diagrams showing the mark cross-section and signal waveform for explaining the principle of the present invention;

FIG. 3 is a block diagram showing the configuration of the signal processing system of a CCD camera;

FIG. 4 is a plan view showing the shot array and mark arrangement on a wafer;

FIG. 5 is a plan view showing the mark arrangement on an index plate;

FIGS. 6(A) and 6(B) are diagrams showing the shape and sectional structure of wafer marks;

FIGS. 7(A) and 7(B) are diagrams showing the arrangements of the index mark and wafer mark during alignment and the waveform of a video signal from the CCD camera;

FIG. 8 is a flowchart showing the procedure of the alignment process in accordance with the method according to an embodiment of the present invention;

FIGS. 9(A) to 9(D), FIGS. 10(A) and 10(B), FIGS. 11(A) and 11(B), FIGS. 12(A) and 12(B) are waveform diagrams showing the states of signal waveform data calculated in the course of process shown in FIG. 8;

FIGS. 13(A) to 13(C) are diagrams showing the structure of an asymmetric mark and the signal waveform thereof;

FIGS. 14 and 15 are diagrams which each explaining the difference in the vernier configurations;

FIG. 16 is a diagram for explaining the vernier reading;

FIG. 17 is a wafer plan view showing the state of the mark becoming asymmetric in the peripheral shots;

FIG. 18 is a diagram for explaining an example of TTR alignment sensor;

FIGS. 19(A) and 19(B) are diagrams showing the sectional structure of a grating mark used for an interference alignment method and the signal waveform thereof;

FIGS. 20(A) to 20(C) are diagrams each showing the variations of the wafer mark shape;

FIG. 21 is a flowchart showing the procedure for selecting the optimum mode by automatically collating the number of wafer marks and that of edge bottom waveforms;

FIG. 22 is a waveform diagram showing an example of processing on the signal waveform in the process shown in FIG. 21;

FIGS. 23(A) and 23(B) are diagrams showing the mark structure for explaining the split top phenomenon of the edge bottom wave and the signal waveform;

FIG. 24 is a perspective view showing another embodiment of the wafer alignment sensor shown in FIG. 1;

FIG. 25 is a plan view showing the mark arrangement on a conjugate index plate suitable for the system shown in FIG. 24;

FIGS. 26 and 27 are diagrams respectively showing the usage of the index mark shown in FIG. 25 and the signal processing method;

FIG. 28 is a plan view showing the relationship between the arrangement of the global alignment marks and the imaging range during the search alignment;

FIGS. 29(A) and 29(B) are diagrams showing an example of the video signal waveform when the wafer shown in FIG. 28 was imaged; and

FIG. 30 is a plan view showing an example of the shot arrangement by the sample alignment with the EGA method.

Description of Major Symbols

| | |
|---|---|
| R | Reticle |
| W | Wafer |
| PL | Projection Lens |
| MK, MD1, MD2, MD3, MD4, MDn, WM, GW, WGM | Wafer Mark |
| TL, TR | Index Mark |
| ST | Wafer Stage |
| 12 | Objective Lens |
| 18 | Conjugate Index Plate |
| 22 | CCD |
| 24 | Optical Fiber for Wideband Illumination Light |
| 42 | Analog-Digital Converter |
| 43 | Memory (RAM) |

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FIG. 2(B)

LEVEL

POSITION SCANNED

FIG. 2(C)

POSITION SCANNED

FIG. 3

48: ADDRESS COUNTER

IFX, IFY: INTERFEROMETER

52: STAGE CONTROLLER

50: PROCESSOR

FIG. 7(A)

N LINES

FIG. 7(B)

SIGNAL LEVEL

POSITION SCANNED (MEMORY ADDRESS VALUE)

FIG. 8

START

100: OBTAIN AVERAGE WAVEFORM DATA BY AVERAGING WAVEFORM DATA FOR PREDETERMINED NUMBER OF SCANNING LINES

104: OBTAIN DIFFERENTIATED WAVEFORM DATA P(N) BY DIFFERENTIATING WAVEFORM DATA

106: DETERMINE POSITION OF PEAK POINT AND BOTTOM POINT FOR DIFFERENTIATED WAVEFORM DATA P(N)

108: SELECT BOTTOM POINT AND PEAK POINT BASED ON THE NUMBER OF INDEX MARKS AND THE NUMBER OF WAFER MARKS

102: OBTAIN SMOOTHED WAVEFORM DATA R(n) BY SMOOTHING AVERAGE WAVEFORM DATA

110: OBTAIN SLICE INTERSECTIONS FOR EACH SLOPE OF SMOOTHED WAVEFORM DATA R(n) BASED ON BOTTOM POINT AND PEAK POINT

112: CALCULATE LENGTH PER PIXEL UNIT BASED ON SPACE Lt OF INDEX MARKS

114: CALCULATE CENTRAL POSITION Ct OF INDEX MARKS

118: CALCULATE CENTER C1 OF WAFER MARK BY USING INNER SLOPE DETECTION METHOD

120: CALCULATE CENTER C1 OF WAFER MARK BY USING OUTER SLOPE DETECTION METHOD

122: CALCULATE CENTER C1 OF WAFER MARK BY USING BOTH SLOPE DETECTION METHOD

124: CALCULATE ALIGNMENT ERROR BY Ct-C1

END

FIG. 9(A)

LEVEL

ADDRESS POINT

AVERAGE WAVEFORM

FIG. 9(D)

ADDRESS POINT

FIG. 10(B)

ADDRESS OF SMOOTHED WAVEFORM DATA

FIG. 12(A)

ADDRESS POINT

FIG. 12(B)

ADDRESS POINT

FIG. 13(C)

LEVEL

POSITION SCANNED (ADDRESS)

FIG. 16

MEASURING DIRECTION

FIG. 19(B)

LEVEL

POSITION SCANNED

FIG. 21

FROM STEP 115

200: OBTAIN CONTRAST VALUES CV1, CVr AT LEFT AND RIGHT POSITIONS SPACED FROM DOWN-SLOPE POSITION BY CONSTANT DISTANCE

208: ALL CHECKED?

OUTER SLOPE DETECTION (TO STEP 120)

INNER SLOPE DETECTION (TO STEP 118)

USER'S SELECTION

FIG. 22

LEVEL

POSITION SCANNED

FIG. 29(A)

LEVEL

POSITION SCANNED

FIG. 29(B)

LEVEL

POSITION SCANNED